Calculator
Announcements
Exceptions
Raise Statements
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`TypeError` -- A function was passed the wrong number/type of argument
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(Demo)
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Handling Exceptions
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(Demo)
Example: Reduce
Reducing a Sequence to a Value
Reducing a Sequence to a Value

```python
def reduce(f, s, initial):
    """Combine elements of s pairwise using f, starting with initial.

    E.g., reduce(mul, [2, 4, 8], 1) is equivalent to mul(mul(mul(1, 2), 4), 8).

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![Diagram of reduce(pow, [1, 2, 3, 4], 2)]
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(Demo)
Programming Languages
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Python 3

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dis import dis
dis(square)
```

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- **Canonical Implementation:** An interpreter or compiler for the language
Parsing
Reading Scheme Lists
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A Scheme list is written as elements in parentheses:
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(<element_0> <element_1> ... <element_n>)
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A Scheme list is written as elements in parentheses:

\[(<\text{element}_0> <\text{element}_1> ... <\text{element}_n>)\]

Each <element> can be a combination or primitive
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\[(\text{element}_0 \ \text{element}_1 \ \ldots \ \text{element}_n)\]

Each \(<\text{element}>\) can be a combination or primitive

\[(+ (* 3 (+ (* 2 4) (+ 3 5))) (+ (- 10 7) 6))\]
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(+ (* 3 (+ (* 2 4) (+ 3 5))) (+ (- 10 7) 6))
```

The task of parsing a language involves coercing a string representation of an expression to the expression itself

(Demo)
Parsing
Parsing

A Parser takes text and returns an expression
A Parser takes text and returns an expression
Parsing

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Parsing

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A Parser takes text and returns an expression

```
'(+ 1'
'  (- 23)'
'  (* 4 5.6))'
```
A Parser takes text and returns an expression

```plaintext
'(+ 1'
'  (- 23)'
'  (* 4 5.6))'
```
A Parser takes text and returns an expression

Text → Lexical analysis → Tokens → Syntactic analysis → Expression

'(+ 1'
'  (- 23)'  →  '(', '+', 1
'  (* 4 5.6))'
A Parser takes text and returns an expression.
Parsing

A Parser takes text and returns an expression

Text → Lexical analysis → Tokens → Syntactic analysis → Expression

'(+ 1'
'(- 23)'
'(* 4 5.6))' → '(', '+', 1
'(', '-', 23, ')
'('
A Parser takes text and returns an expression.

**Text**

- '(+ 1'
- '(- 23)
- '(* 4 5.6))'

**Lexical analysis**

- '(', '+', 1
- '(', '-', 23, ')'

**Tokens**

- '('
- '+'
- 1
- '('
- '-'
- 23
- ',')'

**Syntactic analysis**

- '(', '+', 1
- '(', '-', 23, ',')'

**Expression**
Parsing

A Parser takes text and returns an expression

Text

Lexical analysis

Tokens

Syntactic analysis

Expression

'(+ 1'
'(- 23)'
'(* 4 5.6))'

'(','+','1
'(','-','23',')'
'(','*','4','5.6',')'),'')'
A Parser takes text and returns an expression.
A Parser takes text and returns an expression

- **Lexical analysis**
  - Text
  - Tokens

- **Syntactic analysis**
  - Expression

- **Iterative process**
A Parser takes text and returns an expression

- **Lexical analysis**
  - Tokens
  - Text: '(+ 1' '(- 23)' '(* 4 5.6))'
  - Tokens: '(', '+', 1 '(', '-', 23, ')', '(', '*', 4, 5.6, ')', ')'

- **Syntactic analysis**

  - Iterative process
  - Checks for malformed tokens
A Parser takes text and returns an expression

- **Lexical analysis**
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- Iterative process
- Checks for malformed tokens
- Determines types of tokens
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A Parser takes text and returns an expression.

- **Lexical analysis**
  - Iterative process
  - Checks for malformed tokens
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- **Tokens**

- **Syntactic analysis**
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A Parser takes text and returns an expression

- **Lexical analysis**
  - Text: "(+ 1"
  - Tokens: Pair('+', Pair(1, ...))

- **Syntactic analysis**
  - Expression: Pair('+', Pair(1, ...))

- Iterative process
- Checks for malformed tokens
- Determines types of tokens
- Processes one line at a time

Expression: (+ 1 (- 23) (* 4 5.6))
A Parser takes text and returns an expression

- Iterative process
- Checks for malformed tokens
- Determines types of tokens
- Processes one line at a time

- Tree-recursive process

Text → Lexical analysis → Tokens → Syntactic analysis → Expression

Expression:
Pair('+', Pair(1, ...))

Printed as:
(+ 1 (- 23) (* 4 5.6))
A Parser takes text and returns an expression

- Iterative process
- Checks for malformed tokens
- Determines types of tokens
- Processes one line at a time

- Tree-recursive process
- Balances parentheses
Parsing

A Parser takes text and returns an expression

Text  | Lexical analysis  | Tokens  | Syntactic analysis  | Expression

'(+ 1'
'(- 23)'
'(* 4 5.6)'

'(', '+', 1
'(', '-', 23, ')
'(', '*', 4, 5.6, ')', ')

Pair('+', Pair(1, ...))

printed as
(+ 1 (- 23) (* 4 5.6))

- Iterative process
- Checks for malformed tokens
- Determines types of tokens
- Processes one line at a time

- Tree-recursive process
- Balances parentheses
- Returns tree structure
A Parser takes text and returns an expression

- Iterative process
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Syntactic Analysis
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**Base case:** symbols and numbers
Syntactic Analysis

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Base case: symbols and numbers

Recursive call: scheme_read sub-expressions and combine them
Syntactic Analysis

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Each call to scheme_read consumes the input tokens for exactly one expression

\[\text{'}(\text{', '+', 1, '(', ', '-'', 23, ')}', '(', ', '*', 4, 5.6, ')}', ')']

**Base case:** symbols and numbers

**Recursive call:** scheme_read sub-expressions and combine them
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Syntactic analysis identifies the hierarchical structure of an expression, which may be nested.

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```
'( '+', 1, '( '-', 23, ')', '( '*', 4, 5.6, ')', ')'
```

**Base case:** symbols and numbers

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Syntactic Analysis

Syntactic analysis identifies the hierarchical structure of an expression, which may be nested.

Each call to scheme_read consumes the input tokens for exactly one expression.

```
'( +, 1, ( - , 23 , ) ) , ( * , 4 , 5.6 , ) , )
```

**Base case:** symbols and numbers

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Syntactic Analysis

Syntactic analysis identifies the hierarchical structure of an expression, which may be nested.

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```
'(+, 1, ('-, 23), ('*, 4, 5.6), ')
```

**Base case:** symbols and numbers

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Syntactic Analysis

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```
'(+', '+', 1, '(+', '-', 23, ')'), '(+', '*+', 4, 5.6, ')', ')
```

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```
'(+', '+', 1, '(+', '−', 23, ')', '(+', '*', 4, 5.6, ')', ')
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```

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**Recursive call:** scheme_read sub-expressions and combine them
Scheme-Syntax Calculator

(Demo)
Calculator Syntax
Calculator Syntax

The Calculator language has primitive expressions and call expressions. (That's it!)
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A primitive expression is a number: 2 -4 5.6
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Expression

(* 3
  (+ 4 5)
  (* 6 7 8))
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<tr>
<th>Expression</th>
<th>Expression Tree</th>
<th>Representation as Pairs</th>
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<tbody>
<tr>
<td>(* 3 (+ 4 5) (* 6 7 8))</td>
<td><img src="image" alt="Expression Tree" /></td>
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Calculator Semantics
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+: Sum of the arguments
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- **+**: Sum of the arguments
- **×**: Product of the arguments
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* : Product of the arguments

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The value of a calculator expression is defined recursively.

**Primitive:** A number evaluates to itself.

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- **+**: Sum of the arguments
- **∗**: Product of the arguments
- **−**: If one argument, negate it. If more than one, subtract the rest from the first.
- **÷**: If one argument, invert it. If more than one, divide the rest from the first.

**Expression**

\[
(+\ 5
\quad (*\ 2\ 3)
\quad (*\ 2\ 5\ 5))
\]
Calculator Semantics

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\[
(+ 5 \\
(* 2 3) \\
(* 2 5 5))
\]

\[
+ \\
5
\]

\[
* \\
2 \\
3
\]

\[
* \\
2 \\
5 \\
5
\]
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Expression

\[
(+ 5 \\
(* 2 3) \\
(* 2 5 5))
\]

Expression Tree

```
+ \\
5 6 \\
* 2 3 \\
* 2 5 5
```
Calculator Semantics

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- : Sum of the arguments
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<td>( (+ 5 ) )</td>
<td>+ 5</td>
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<tr>
<td>( (\ast 2 3) )</td>
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</tr>
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\[ (+ 5 \quad (*) 2 \ 3 \quad (*) 2 \ 5 \ 5) \]

Expression

Expression Tree
Evaluation
The Eval Function
The Eval Function

The eval function computes the value of an expression, which is always a number.
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It is a generic function that dispatches on the type of the expression (primitive or call).
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### Implementation

```python
def calc_eval(exp):
    if isinstance(exp, (int, float)):
        return exp
    elif isinstance(exp, Pair):
        arguments = exp.rest.map(calc_eval)
        return calc_apply(exp.first, arguments)
    else:
        raise TypeError
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### Language Semantics
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### Language Semantics

- **A number evaluates**... to itself
- **A call expression evaluates**... to its argument values combined by an operator

Recursive call returns a number for each operand
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  - to its argument values combined by an operator
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```

**Language Semantics**

- A number evaluates... to itself
- A call expression evaluates... to its argument values combined by an operator

Recursive call returns a number for each operand

'+' , '-', '*', '/'
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A Scheme list of numbers

Recursive call returns a number for each operand
Applying Built-in Operators
Applying Built-in Operators

The apply function applies some operation to a (Scheme) list of argument values
Applying Built-in Operators

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In calculator, all operations are named by built-in operators: +, −, *, /
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### Implementation

```python
def calc_apply(operator, args):
    if operator == '+':
        return reduce(add, args, 0)
    elif operator == '-':
        ...
    elif operator == '*':
        ...
    elif operator == '/':
        ...
    else:
        raise TypeError
```

### Language Semantics
Applying Built-in Operators

The apply function applies some operation to a (Scheme) list of argument values.

In calculator, all operations are named by built-in operators: +, −, *, /

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</tr>
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</tr>
<tr>
<td>elif operator == '-':</td>
<td></td>
</tr>
<tr>
<td>...</td>
<td></td>
</tr>
<tr>
<td>elif operator == '*':</td>
<td></td>
</tr>
<tr>
<td>...</td>
<td></td>
</tr>
<tr>
<td>elif operator == '/':</td>
<td></td>
</tr>
<tr>
<td>...</td>
<td></td>
</tr>
<tr>
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Applying Built-in Operators

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In calculator, all operations are named by built-in operators: +, −, *, /

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    elif operator == '-':
        ...
    elif operator == '*':
        ...
    elif operator == '/':
        ...
    else:
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```

**Language Semantics**

```
+: 
   Sum of the arguments
```
Applying Built-in Operators

The apply function applies some operation to a (Scheme) list of argument values.

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**Implementation**

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        ...
    elif operator == '*':
        ...
    elif operator == '/':
        ...
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```

**Language Semantics**

+:
  
  *Sum of the arguments*

−:
  ...

∗:
  ...

/:
  ...

else:
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Applying Built-in Operators

The apply function applies some operation to a (Scheme) list of argument values.

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<tr>
<td><em>elif</em> operator == '-':</td>
<td></td>
</tr>
<tr>
<td>⋮</td>
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</tr>
<tr>
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<tr>
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</tr>
<tr>
<td><em>elif</em> operator == '/':</td>
<td><em>⋯</em></td>
</tr>
<tr>
<td>⋮</td>
<td><em>⋯</em></td>
</tr>
<tr>
<td><em>else:</em></td>
<td></td>
</tr>
<tr>
<td><em>raise</em> TypeError</td>
<td></td>
</tr>
</tbody>
</table>

(Demo)
Interactive Interpreters
Read-Eval-Print Loop
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The user interface for many programming languages is an interactive interpreter.
Read-Eval-Print Loop

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1. Print a prompt
Read-Eval-Print Loop

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(Demo)
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Exceptions are raised within lexical analysis, syntactic analysis, eval, and apply
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Example exceptions
Raising Exceptions

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- **Syntactic analysis**: An extra ) raises SyntaxError("unexpected token")
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• **Eval**: An empty combination raises TypeError("() is not a number or call expression")
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(Demo)
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(Demo)